Xenomai 3 – An Overview of the Real-Time Framework for Linux

Xenomai 3 – An Overview of the Real-Time Framework for Linux

Agenda

- **Project introduction**
- Co-Kernel technology, now and then
- Xenomai 3 for native Linux
- Improving co-kernel integration
- Summary

What is Xenomai?

- **Old-style real-time extension for Linux?**
- **Something like / a fork of RTAI?**
- **Requires real-time applications to be kernel modules?**
- **…?**

Xenomai is an RTOS-to-Linux Portability Framework

It now comes in two flavors

- As **co-kernel** extension for (patched) Linux
- As libraries for **native Linux** (including PREEMPT-RT)

Xenomai History

Xenomai 1.0

- Announced in 2001 – as portability framework for RTOS applications
- Required a real-time basis
- Development of ADEOS layer for Linux and RTAI
- Merged with RTAI => RTAI/fusion

Xenomai 2.0

- Departed from RTAI in 2005 – incompatible design goals
- Evolved ADEOS to I-pipe layer (also used by RTAI)
- Ported to 6 architectures

Xenomai 3.0

- Released in 2015 after >5 years of development
- Rework of in-kernel core (now POSIX-centric)
- Support for native Linux

People behind Xenomai

Philippe Gerum	**–**	**Project founder and maintainer**
Gilles Chanteperdrix	**–**	**ARM, x86 archs, Xenomai 2 & 3 core, RTnet**
Alexis Berlemont	**–**	**Analogy stack**
Jorge Ramirez-Ortiz	**–**	**Analogy stack**
Wolfgang Grandegger	**–**	**Real-time CAN**
Jan Kiszka	**–**	**RTDM, x86 arch, assorted**

et al.

Xenomai Applications

- **Machine control systems, PLCs**
- **Printing machines** (manroland)
- **Printers / copying machines**
- **Network switches** (e.g. Ruggedcom)
- **Magnetic resonance tomographs** (Siemens Healthcare)
- **OROCOS** (OSS robotics framework)
- **Robotic research projects**
- **…** (many, many incognito applications)

Xenomai 3 – An Overview of the Real-Time Framework for Linux

Agenda

Project introduction

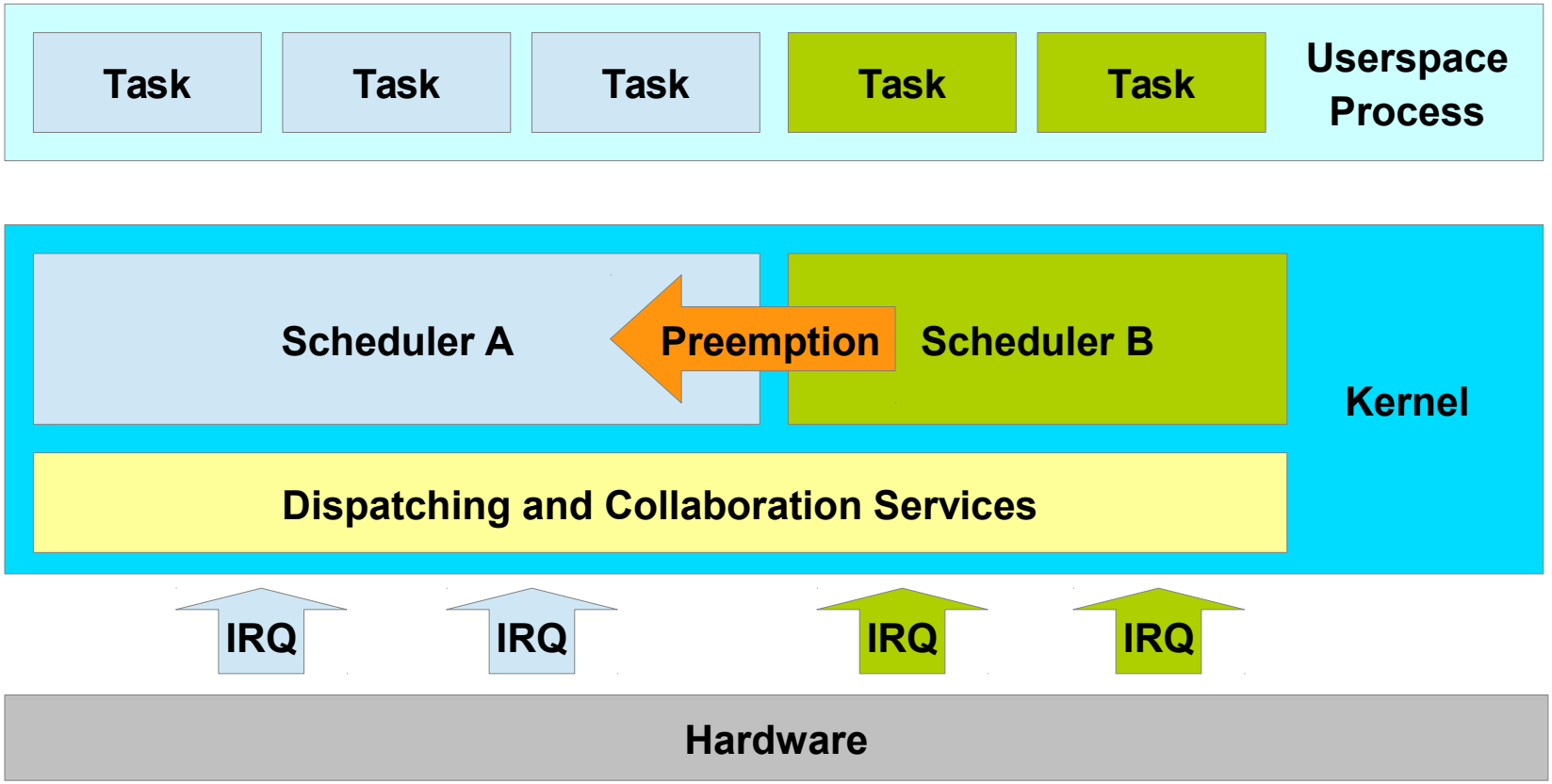
Co-Kernel technology, now and then

Xenomai 3 for native Linux

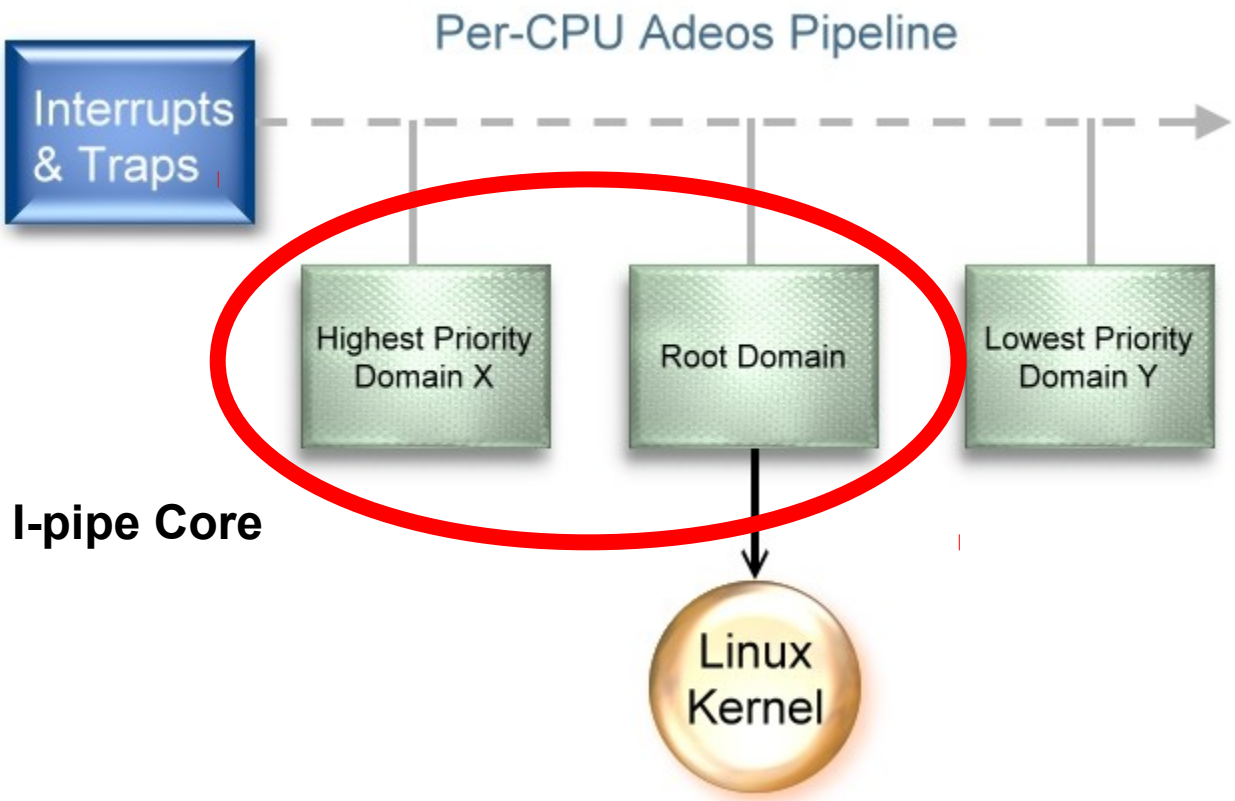
Improving co-kernel integration

Summary

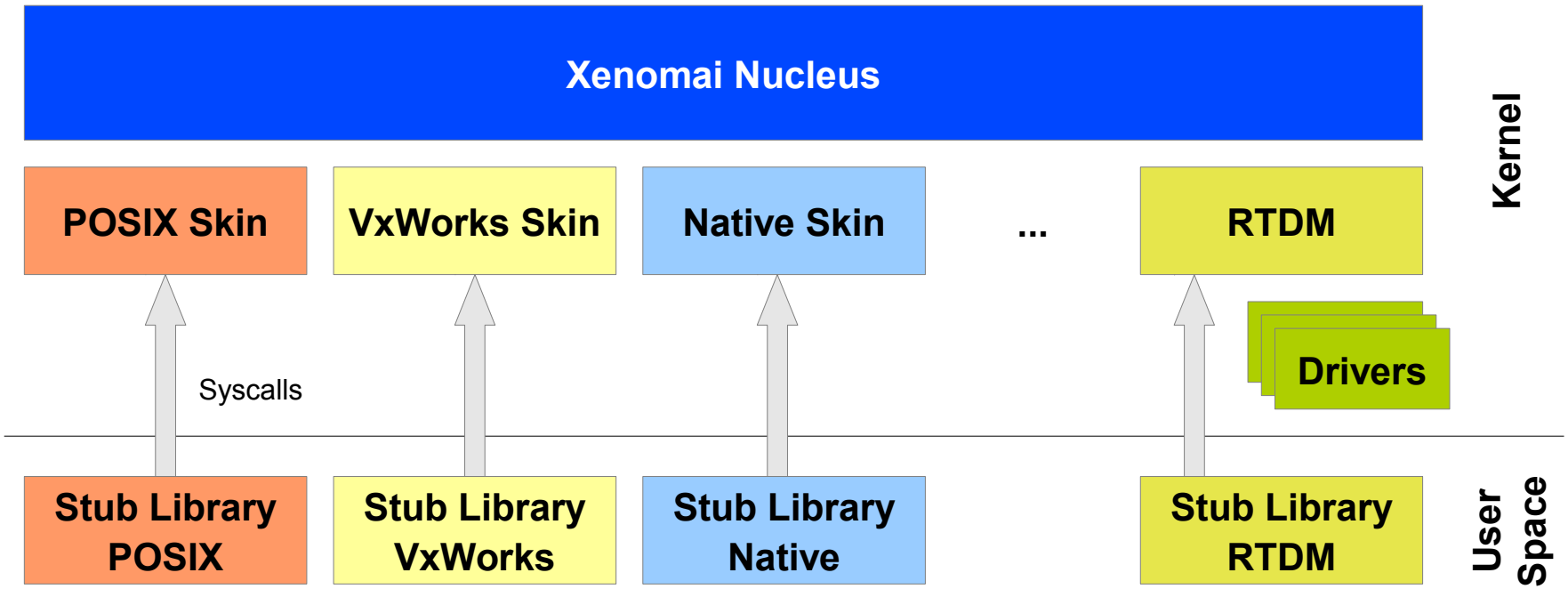
What is a Co-Kernel?



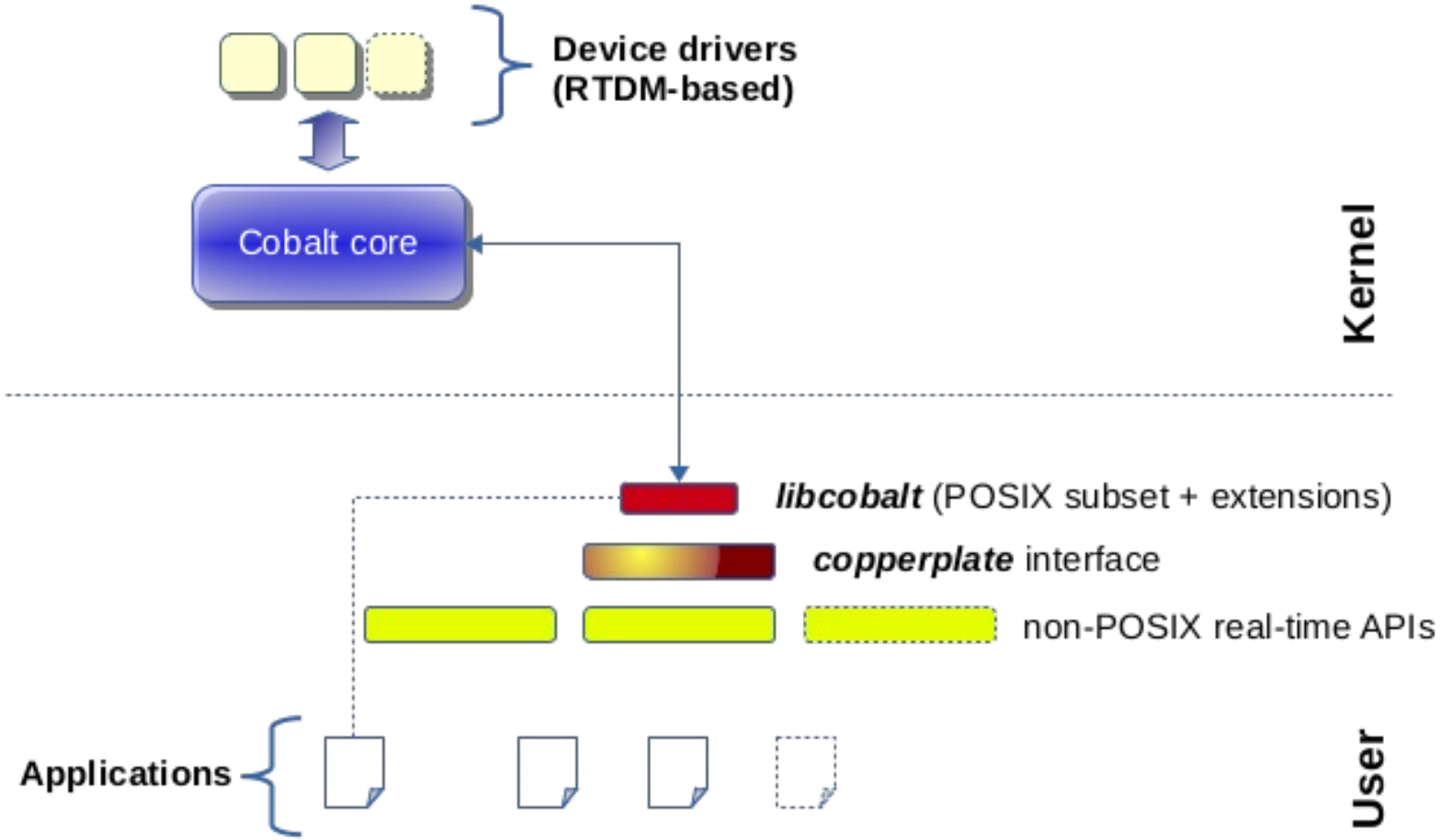
Interrupt and Trap Dispatching – from Adeos to I-pipe Core



Xenomai 2 Co-Kernel Architecture



Cobalt: Real-Time Co-Kernel for Linux



Cobalt's Application Interface

Dispatching problem

- Both Cobalt and libc provide POSIX implementations
- How do RT application pick the right one?

Solution: symbol wrapping

- Example pthread_mutex_lock → __wrap_pthread_mutex_lock
- libcobalt provides __wrap_*, forwards unhandled invocations to libc
- No source code changes to POSIX applications required
- Some additional services available (*_np)

Supported architectures

- ARM (32 bit, 64 bit upcoming)
- Blackfin
- PowerPC (32 bit, 64 bit)
- x86 (32 bit, 64 bit, 32-on-64 bit, x32)

Migrating Threads between Cobalt and Linux

Preserve Linux service for Cobalt threads

- Linux syscalls
- Fault and trap handling
- Handling of asynchronous signals

Solution: every cobalt thread is also a Linux task

- Share thread states
- Only one can run at a time
- Migration to RT: suspend Linux task, resume Cobalt thread
- Migration to Linux (on syscall, fault/trap, signal):
  suspend Cobalt thread, resume Linux task

Real-Time Driver Model (RTDM)

Goals and principles

- Provide environment for co-kernel real-time drivers
  - Service interface towards applications and other drivers
  - Low-level primitives from implementing drivers
- Reuse Linux for non-RT purposes
  (setup / shutdown, resource discovery and claiming, etc.)

Two types of RTDM devices

- Character device (open/close, read, write, ioctl)
- Protocol device (socket, bind, send, recv, etc.)

Device profiles

- Character: UART, UDD (analogous to UIO), Memory, ...
- Protocol: UDP/TCP (RTnet), CAN, IPC, ...

Tooling with Cobalt

Debugging

- gdb works
- Improvements on synchronous stop/resume are work in progress

Tracing

- ftrace (tracecmd & Co.)
- I-pipe latency tracer (low-level latency hunts)

Valgrind / Helgrind

- No support because of unknown syscalls
- Alternative: Mercury (native support)
- Limited suitability for RT applications in general

Hardening Your RT Application with Cobalt

Cobalt fosters clear RT/non-RT split

- RT = everything that runs against cobalt, non-RT = all the rest
- Migrations can trigger debug signal

SIGDEBUG (SIGXCPU)

- Usage: enable when RT thread enters time-critical phase
- Signal reasons
  - SIGDEBUG_MIGRATE_SIGNAL (Linux signal pending)
  - SIGDEBUG_MIGRATE_SYSCALL (Linux syscall invoked)
  - SIGDEBUG_MIGRATE_FAULT (page fault etc. triggered)
  - SIGDEBUG_MIGRATE_PRIOINV (RT thread waits for migrated thread)
  - SIGDEBUG_WATCHDOG (RT thread starves Linux)
- Instrumentation of lazily migrating malloc/free

Agenda

Project introduction

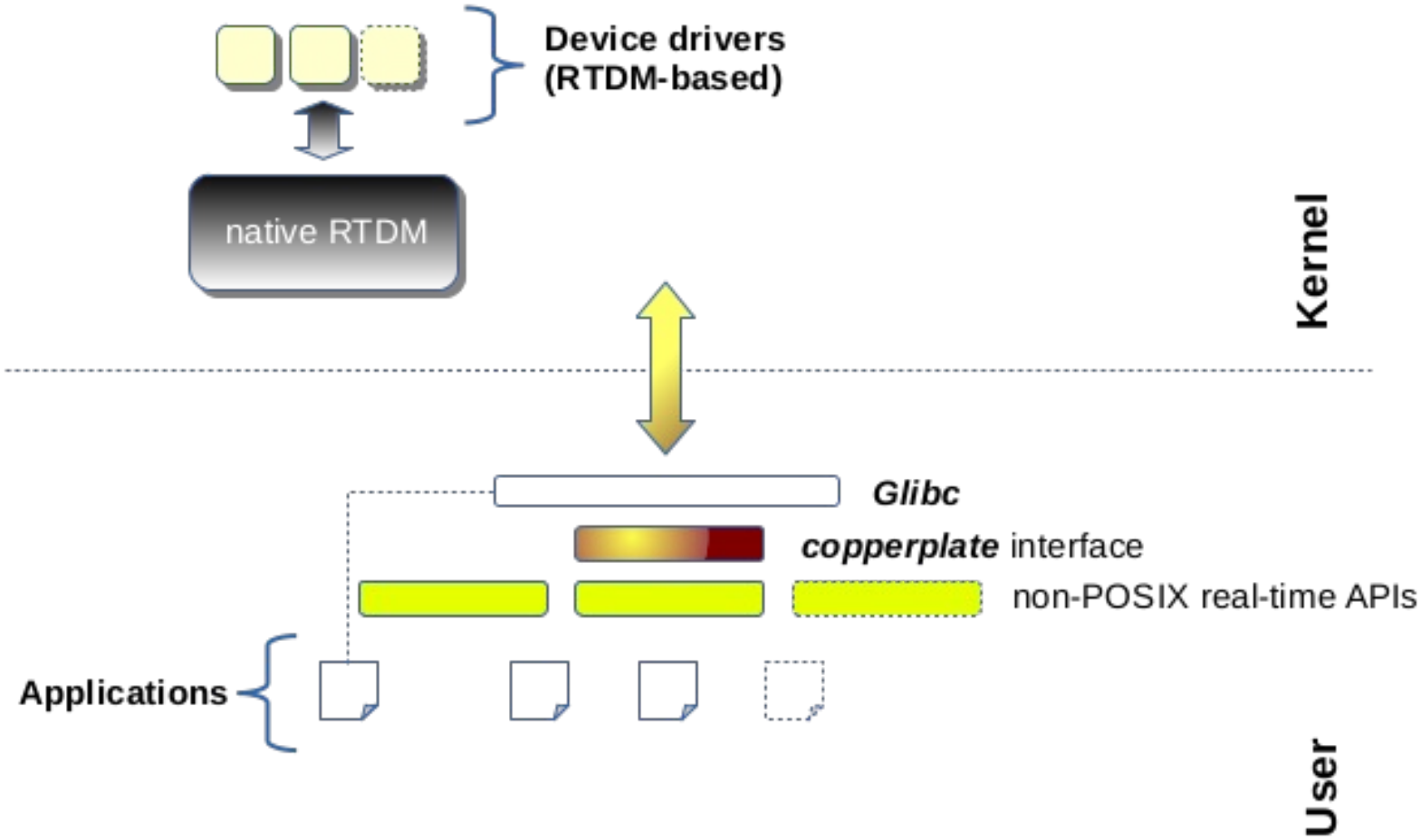
Co-Kernel technology, now and then

Xenomai 3 for native Linux

Improving co-kernel integration

Summary

Mercury: RTOS API Emulation for Native Linux



Mercury Details

Vision and goals

- Run API emulation over standard Linux/POSIX
- Enable seamless migration between co-kernel and native Linux deployments

Status

- 3 real-time APIs available
  - VxWorks
  - pSOS
  - Alchemy (former “native skin”)
- Native RTDM layer yet missing
  - Preexisting work by Wolfgang Grandegger, need update
  - Shall enable usage of all RTDM drivers under Linux (RTnet, Analogy, ...)

Do We Still Need a Co-Kernel?

Functional limitations of Mercury

- Emulation of RTOS scheduling behavior limited by Linux scheduler
- Not all kernel+libc code paths used by Mercury are necessarily hard real-time under PREEMPT-RT
- Application use of non-RT services harder to identify

Performance limitations of Mercury / PREEMPT-RT

- Co-kernel usually more light-weight on low-end platforms (limited caches vs. code path lengths)
- PREEMPT-RT can have unwanted impact on co-located non-RT workloads

Xenomai 3 – An Overview of the Real-Time Framework for Linux

Agenda

Project introduction

Co-Kernel technology, now and then

Xenomai 3 for native Linux

Improving co-kernel integration

Summary

The Dark Side of the Co-Kernel: Patch Maintenance

Limited availability of patches

- Current (release 3.0.2) support available for 3.10.32, 3.14.44, 3.18.20, 4.1.18
- Patches usually do not target latest stable
- Self-made updates (e.g. 4.1.18 → .20) often feasible but not broadly tested
- And then there are “nice” vendor trees...

Changes to critical subsystems regularly cause regressions

- Subtle breakages in IRQs, syscalls, memory management possible
- New kernel features have incompatible side effects

Porting efforts consume core developer resources

- Most work done by Philippe and Gilles so far
- Time would be better spent on feature improvements...

Project “Dovetail”

Goals

- Reduce maintenance efforts of co-kernel
- Make hooks/extension separate, more upstream palatable features

Main elements

- IRQ pipeline
- Co-kernel extensions
  - Scheduler transitions for tasks
  - Sharing of CPU traps (incl. Syscalls)
  - Collaborative task management (affinity, context switch, signals, exit)
  - Process memory pinning (eagerly spread ioremap/vmalloc mappings)
  - IRQ muting
  - ...
- Extended use of kernel infrastructure for Xenomai core

Agenda

Project introduction

Co-Kernel technology, now and then

Xenomai 3 for native Linux

Improving co-kernel integration

Summary

Summary

- **Xenomai adds value to Linux**
  - Portability framework
    from classic RTOS's to Linux
  - Co-kernel approach can be beneficial
    for low latencies and real-time application architecture
- **Version 3 renovates and expands Xenomai**
  - Support for RTOS API emulation on top of native Linux & PREEMPT-RT
  - New architecture simplifies and improves co-kernel support
- **“Dovetail” aims at easing co-kernel maintenance**
  - Clearer feature separation
  - Better integration with Linux infrastructure
  - Propose for upstream merge???

Any Questions?

Thank you!

http://xenomai.org

Jan Kiszka <jan.kiszka@siemens.com>
Xenomai mailing list <xenomai@xenomai.org>

Glossary

Cobalt	–	Co-kernel variant of Xenomai 3
Mercury	–	Native Linux variant of Xenomai 3
Alchemy	–	Xenomai-own real-time API
Copperplate	–	Library layer for building RTOS APIs
Boilerplate	–	Internal utility Library
Trank	–	Library to support porting from Xenomai 2 to 3
RTDM	–	Real-Time Driver Model, kernel API that enables RT drivers, specifically for Cobalt
Analogy	–	RTDM drivers for digital/analogue converters
Adeos	–	Original interrupt pipeline for Linux, used by early Xenomai 2 versions
I-pipe	–	Evolution and simplification of Adeos
Dovetail	–	New architecture of Linux extensions to hook Xenomai 3 into Linux